INTEGRATED CIRCUIT WITH HIGH-VOLTAGE, LOW-CURRENT POWER SUPPLY DISTRIBUTION AND METHODS OF USING THE SAME

FIELD OF THE INVENTION

[0001] The invention relates to power supply distribution in integrated circuits (ICs). More particularly, the invention relates to an IC in which power is first distributed internally at a first voltage level, then is reduced to a second voltage level (the operating voltage level) for local distribution.

BACKGROUND OF THE INVENTION

[0002] Power supply distribution is an increasingly important consideration in ICs. Given equal power consumption between two ICs, the current that must be supplied to each IC is inversely proportional to the supply voltage level. Transistor sizes in ICs are smaller than they used to be, and the trend is expected to continue. Smaller transistors necessitate smaller supply voltages. Therefore, supply voltages are lower than was previously the case, resulting in larger current consumption within the ICs. Further, power consumption in ICs is not remaining constant with time. Instead, power consumption is on the rise, exacerbating the problem of higher IC currents.

[0003] High current levels in ICs can cause several problems. For example, the voltage drop across a resistor is proportional to the current flow through the resistor. Thus, when a high current flows within the power supply distribution network of an IC, the resistive voltage drops are larger and can affect reliability and timing in the affected portions of the IC. For example, with sufficiently large currents, metal traces commonly used to distribute a voltage supply on an IC can have sufficient resistance to adversely affect the functionality of the IC. One solution to this problem is to widen the metal traces distributing

power at voltage level VREG within the IC (e.g., see wide metal traces 102, 104 in Fig. 1).

[0007] Due in part to the wide metal traces needed to distribute power, it is becoming impractical to locate power pads around the periphery of a die. The width of the metal traces required to support the necessary current is becoming prohibitive. Therefore, some IC manufacturers have begun to distribute power pads within the core of the die, i.e., in the interior portion of the IC away from the periphery. The technique of distributing the power pads within the core significantly shortens the distance traversed by the wide metal traces, and therefore reduces the die area consumed by the traces. Resistive voltage drops through the traces are also reduced. The resulting ICs are packaged using flip-chip methods that enable connection of the package pins (e.g., balls in a ball grid array package) to the distributed power pads.

[0008] However, there are drawbacks to this approach as well. Distributed power pads can create difficulties with die-on-die multi-chip module techniques, in which IC dice are stacked vertically together. When dice are stacked vertically, power pads away from the periphery of the dice can be made inaccessible.

[0009] Therefore, it is desirable to provide methods and structures for distributing power within an IC that have reduced metal-width requirements. It is further desirable to provide methods and structures for distributing power within an IC that do not require that power pads be distributed within the core of the IC (i.e., away from the periphery of the die).

SUMMARY OF THE INVENTION

[0010] The invention provides methods of distributing power within an integrated circuit (IC) by distributing power at a first voltage level to a plurality of power converters distributed across the IC, converting the first voltage level

[0018] Fig. 6 illustrates the steps of a method of distributing power within an IC according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0019] In the following description, numerous specific details are set forth to provide a more thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention can be practiced without these specific details.

[0020] As noted above, at constant power, current increases as voltage decreases. Therefore, it is desirable to distribute power at higher voltages than might actually be required at the destination. An example of this principle is the electrical power grid used to distribute power to destinations across the country and within cities. Power is broadly distributed at a very high voltage, then the voltage level is dropped using transformers prior to distribution at the local level.

[0021] The present invention applies this principle to power distribution within integrated circuits (ICs). An IC includes power pads, a first power network coupled to the power pads, power converters, and localized power networks. The power converters can be of any type suitable to the application, e.g., DC-to-DC converters or AC-to-DC converters. For example, the power converters can be "buck" converters implemented as switching regulators, such as are well known in the relevant arts. The power converters receive power from the first network, reduce the voltage level to the operating voltage of the IC circuitry, and provide the power to the localized networks at the reduced voltage level. Thus, unlike in known ICs, the first power network distributes power at a higher voltage level than the operating voltage. Hence, the power distribution network carries less current than in known ICs.

converters can then be used to separately alter the power level to suit the requirements of both the I/O circuits and the internal circuits.

[0026] Referring again to Fig. 3, note that the metal traces in the first power network (e.g., 302) are narrower than corresponding metal traces in IC 100 of Fig. 1. Narrower metal traces can be used in IC 300 because less current is carried by the power distribution system of IC 300.

[0027] A further advantage of the power distribution system of Fig. 3 is that power voltage levels are more uniform in the localized power networks (e.g., 303) than is generally the case in prior art ICs (e.g., localized network 103 of Fig. 1). This uniformity is due to the fact that the voltage level generated by each power converter is independent of the input voltage level. Hence, variations in input voltage caused by, for example, varying currents causing varying resistive voltage drops in the first power network, have no effect on the voltage levels provided to each localized power network.

[0028] Fig. 3a shows an exemplary power converter that can be used, for example, to implement power converters 305a-305h of Fig. 3. The power converter of Fig. 3A is a well known "buck" or switching regulator converter, which includes a switch 311, an inductor 312, a diode 313, and a capacitor 314. Switch 311 is coupled between input terminal VIN and a node A. Switch 311 can be controlled, for example, by a pulse width modulator (not shown), such as are well known in the relevant arts. The pulse width modulator provides a pulse having a width that determines the relationship between the input voltage VIN and the output voltage VOUT. If the output voltage VOUT is too high, the pulse width is narrowed, delivering less current and power to the output terminal. If the output voltage VOUT is too low, the pulse is widened to deliver more current and power to the output terminal. Diode 313 is coupled between node A and ground GND. Inductor 312

logic device (PLD), and configuration data bits of the PLD can be used to control the voltage levels supplied by the power converters. The power converters can be controlled together (e.g., by one or more configuration bits that control the output voltage level of all of the power converters), or separately. In embodiments where the power converters are separately controlled, different areas of the IC can operate at different voltage levels. Thus, power consumption in the IC can be reduced by locally decreasing the operating voltage in circuits that need not operate at maximum speed. Reducing the power consumption can, in turn, eliminate or reduce the need for a heat sink, or extend the battery life in battery-powered equipment. Power converters having programmable output voltages are known in the relevant arts. Any such appropriate power converters can be used in accordance with the present invention.

[0033] Fig. 5 illustrates another embodiment, in which the power pads of the IC are not coupled together. Thus, the first power network includes several isolated power traces (e.g., power trace 510). Additionally, in the embodiment of Fig. 5 the power pads and the inductor pads are all mounted near the periphery of the die. However, in other embodiments some or all of the inductor pads, and/or some or all of the power pads, are distributed within the core of the IC. While the invention facilitates the use of peripheral pads, the placement of the pads is not so limited. The system illustrated in Fig. 5 includes an inductor 509a-509h associated with each power converter 305a-305h. Inductors 509a-509h can be implemented as part of the IC, implemented externally to the IC but mounted within the IC package, or implemented externally to the IC and mounted outside the IC package.

[0034] Note that Figs. 3-5 illustrate only a few of the possible configurations for ICs and systems in which the invention can be applied. It will be apparent to one skilled in the art after reading this specification that the present

CLAIMS

What is claimed is:

1. A method of distributing power within an integrated circuit (IC) comprising a plurality of power converters and a plurality of localized power networks each coupled to an associated one of the power converters, the method comprising:

distributing power at a first voltage level to the plurality of power converters;

converting, in each of the power converters, the first voltage level to a second voltage level lower than the first voltage level; and

distributing power at the second voltage level from the power converters via the localized power networks to a plurality of destinations within the IC.

2. The method of Claim 1, wherein:

converting, in each of the power converters, the first voltage level to the second voltage level comprises passing power through an associated inductor.

3. The method of Claim 2, wherein the associated inductor for each power converter is implemented externally to the IC.

4. The method of Claim 1, wherein converting the first voltage level to a second voltage level lower than the first voltage level is performed using switching regulators.

5. The method of Claim 1, wherein the IC is a programmable logic device (PLD), and the method further comprises:

configuring the IC to select the second voltage level.

14. The IC of Claim 8, wherein the power converters are DC-to-DC converters.

15. A system, comprising:
a power supply; and
an integrated circuit (IC), the IC comprising:
a plurality of power pads coupled to the power supply;
a plurality of localized power networks; and
a plurality of power converters coupled to reduce a power level between the power pads and the localized power networks, each power converter having an input terminal coupled to at least one of the power pads and an output terminal coupled to one of the localized power networks.

16. The system of Claim 15, wherein:
the IC further comprises a respective pair of inductor pads coupled to each of the power converters; and
the system further comprises a plurality of inductors, each inductor being coupled between an associated pair of the inductor pads.

17. The system of Claim 15, wherein each power converter is a switching regulator converter.

18. The system of Claim 15, wherein the power pads are disposed around the periphery of the IC.

19. The system of Claim 15, wherein at least some of the power pads are disposed within the core of the IC.

27. The IC of Claim 23, wherein:

the IC is a programmable logic device (PLD); and

the IC further comprises means for configuring the IC to select the second voltage level.

28. The IC of Claim 27, wherein the means for configuring the IC to select the second voltage level comprises means for selecting different second voltage levels for at least two of the power converters.

29. The IC of Claim 23, wherein the power converters are DC-to-DC converters.

30. A system, comprising:

a power supply; and

an integrated circuit (IC), the IC comprising:

a plurality of power pads each coupled to the power supply;

a plurality of power destinations;

a plurality of power converters coupled to receive power at a first voltage level and to provide power at a second voltage level lower than the first voltage level;

a first power network coupled to provide power at the first voltage level from the power pads to the power converters; and

a plurality of second power networks each coupled to provide power at the second voltage level from one of the power converters to a subset of the power destinations.

31. The system of Claim 30, wherein:

the IC further comprises a respective pair of inductor pads coupled to each of the power converters; and

the system further comprises a plurality of inductors, each inductor being coupled between an associated pair of the inductor pads.

INTEGRATED CIRCUIT WITH HIGH-VOLTAGE, LOW-CURRENT POWER SUPPLY DISTRIBUTION AND METHODS OF USING THE SAME

ABSTRACT

Methods of distributing power within an integrated circuit (IC) include distributing power at a first voltage level to a plurality of power converters distributed across the IC, converting the first voltage level to a second and lower voltage level in the power converters, and distributing power at the second voltage level from the power converters via localized power networks to destinations disposed within the IC. The power converters can be of any type suitable to the application, e.g., DC-to-DC converters or AC-to-DC converters. According to another aspect, an IC includes a plurality of power pads, a plurality of localized power networks, and a plurality of power converters coupled to reduce a power level between the power pads and the localized power networks. Each power converter has an input terminal coupled to at least one of the power pads and an output terminal coupled to one of the localized power networks. In some embodiments, the IC is a programmable logic device, and the second voltage level can be configurably selected.

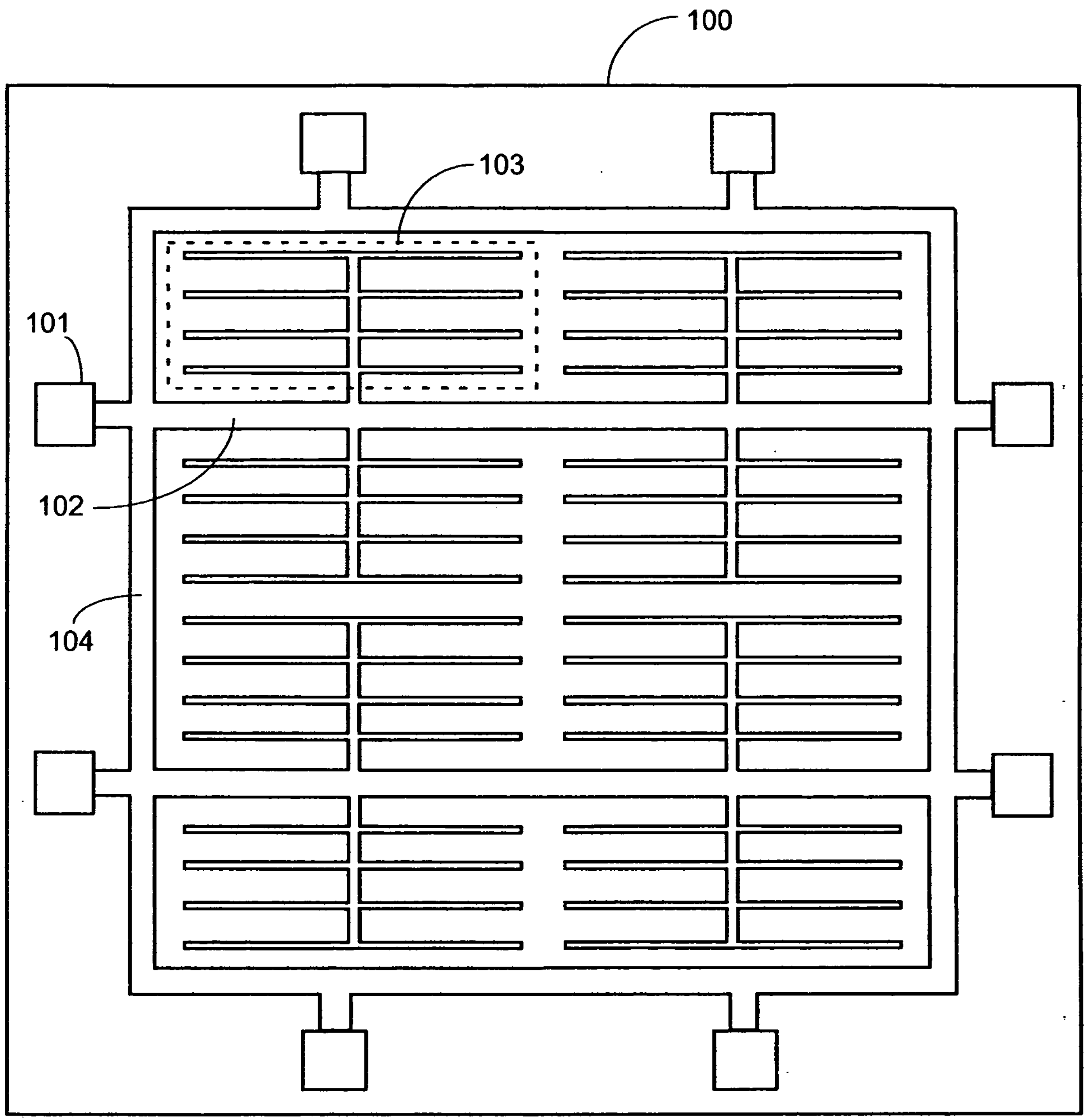


FIG. 1
(Prior Art)

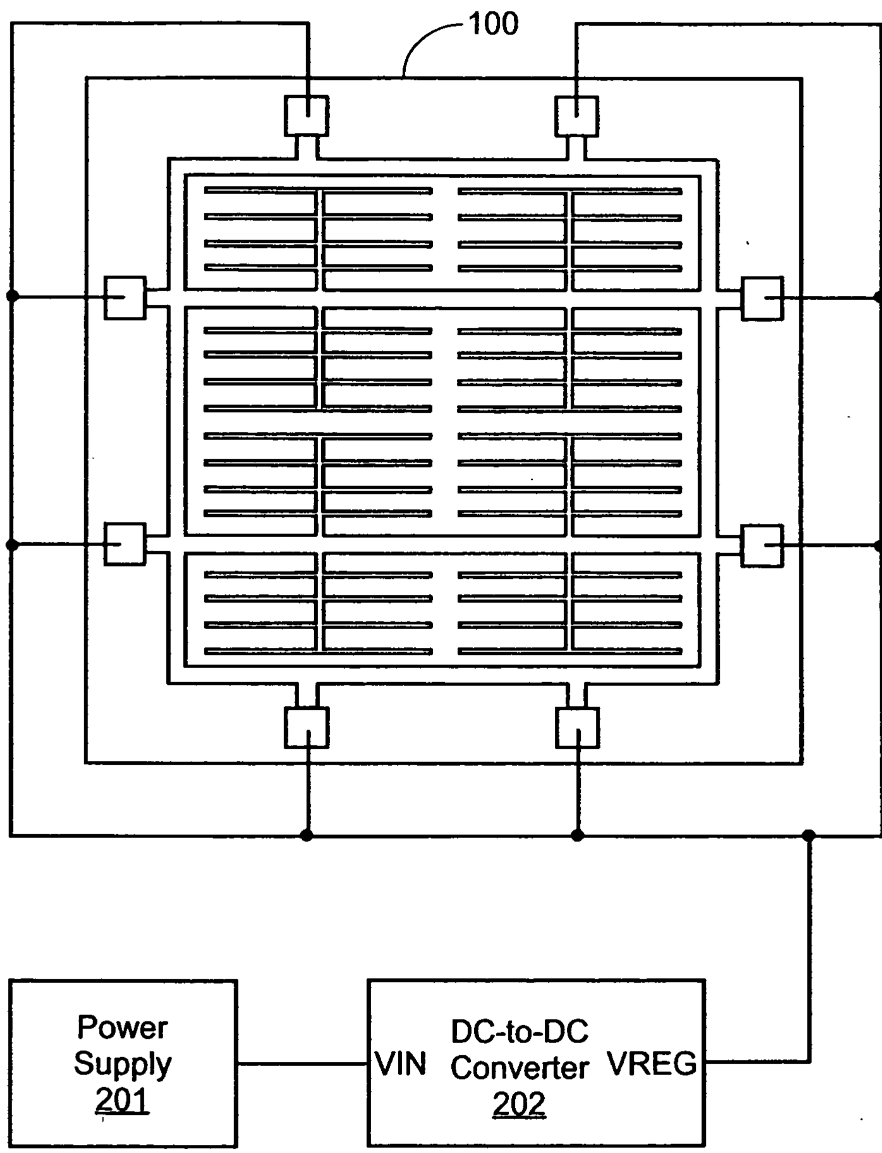


FIG. 2
(Prior Art)

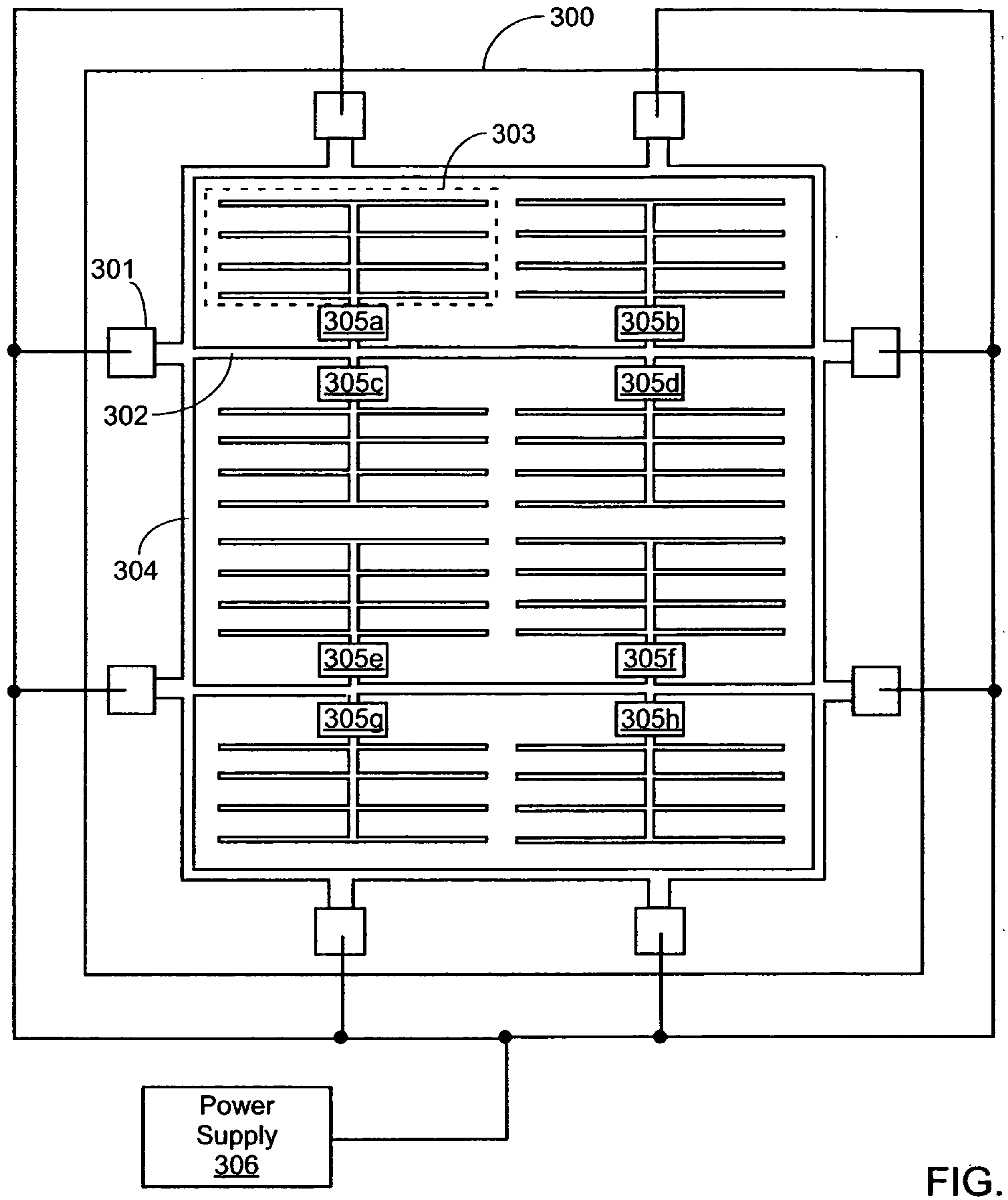


FIG. 3

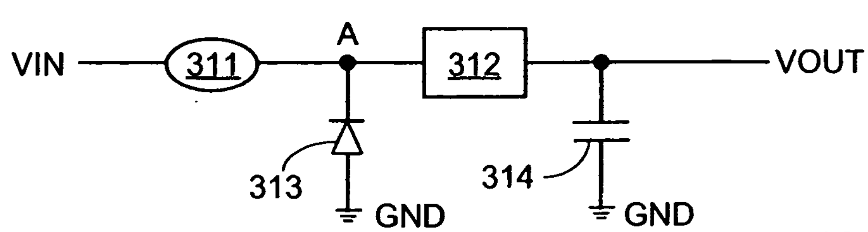


FIG. 3A (Prior Art)

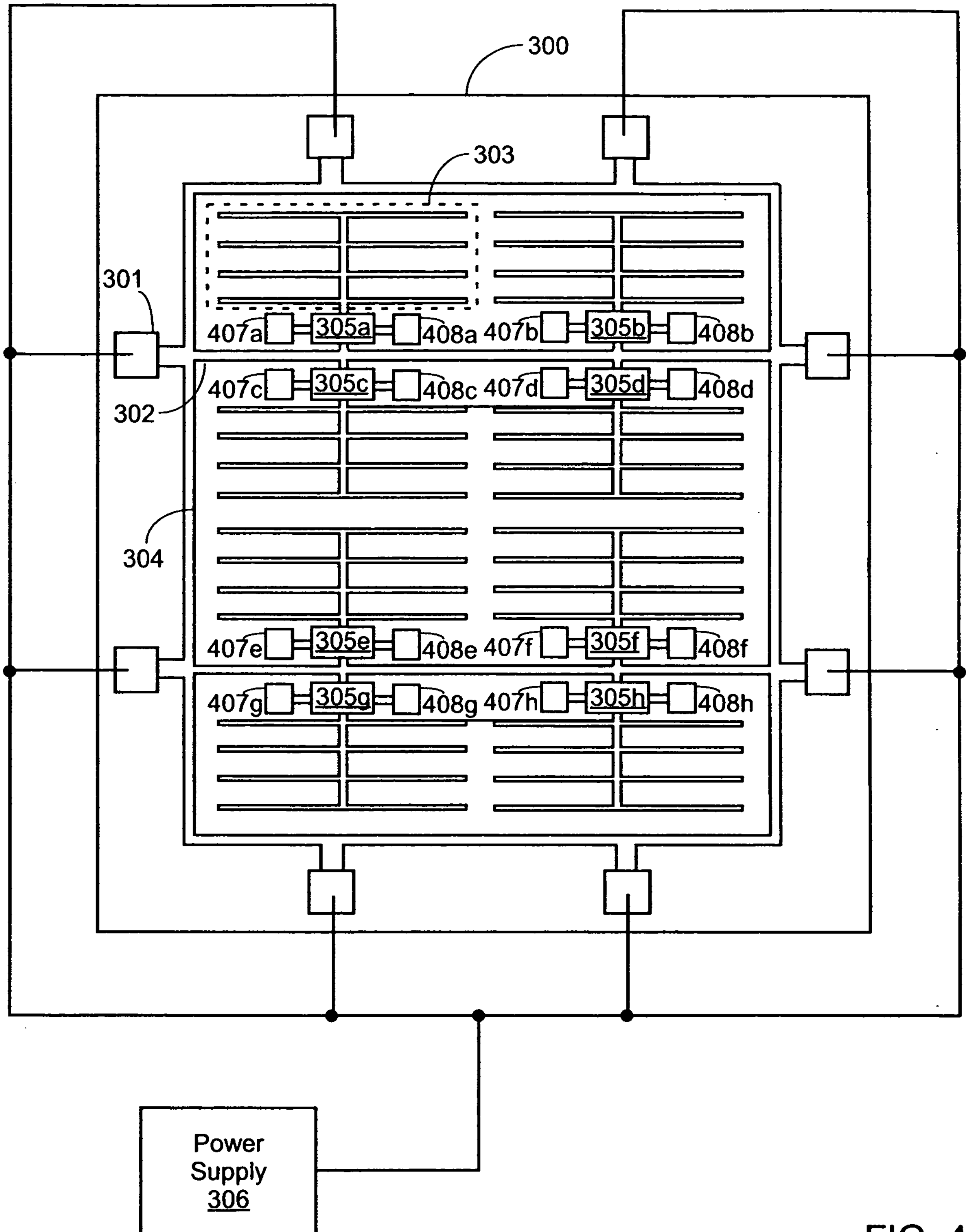
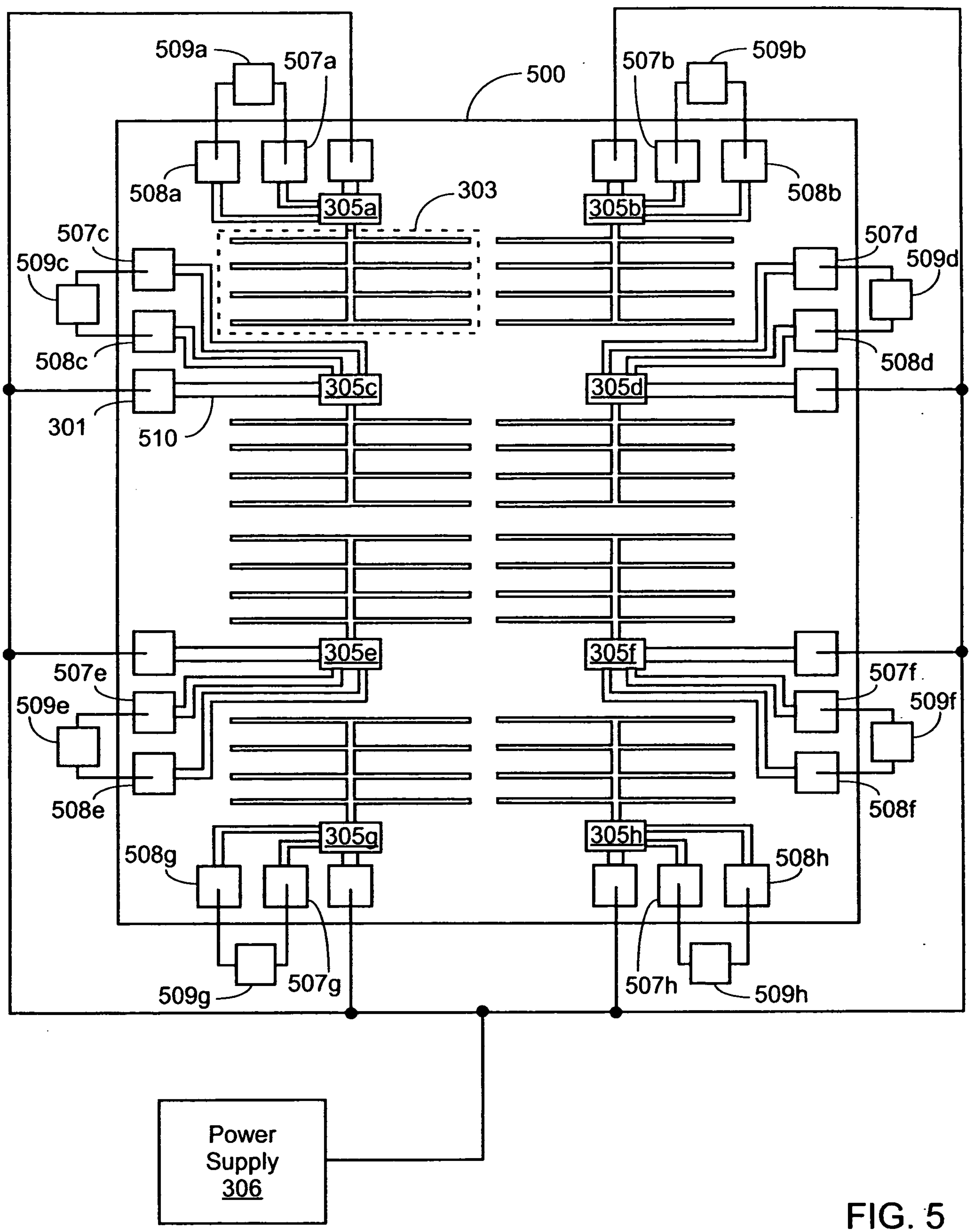

300
303
301
302
304
407a
305a
408a
407b
305b
408b
407c
305c
408c
407d
305d
408d
407e
305e
408e
407f
305f
408f
407g
305g
408g
407h
305h
408h
Power
Supply
306

FIG. 4



509a
507a
500
507b
509b
508a
305a
303
305b
508b
507c
509c
507d
509d
508c
508d
305c
305d
301
510
305e
305f
507e
507f
509e
509f
508e
508f
305g
305h
508g
508h
509g
507g
507h
509h
Power
Supply
306

FIG. 5

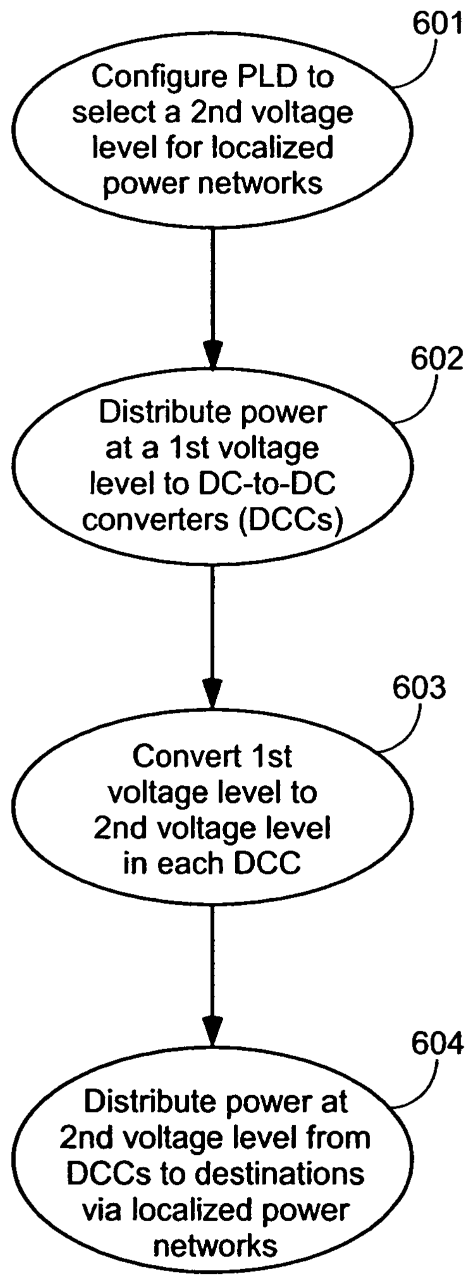

601
Configure PLD to select a 2nd voltage level for localized power networks
602
Distribute power at a 1st voltage level to DC-to-DC converters (DCCs)
603
Convert 1st voltage level to 2nd voltage level in each DCC
604
Distribute power at 2nd voltage level from DCCs to destinations via localized power networks

FIG. 6